Transport Pathways from the Eurasian Basin to the Canadian Basin of the Arctic Ocean and Submarine-Based Acoustic Doppler Current Profiler (ADCP) Measurements of The Upper Arctic Ocean

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LONG-TERM GOAL

Long-term goals have been to better document and understand circulation patterns and mixing processes in the Arctic Ocean. Emphases have been on the roles of small-scale and mesoscale processes in effecting water, heat and material transports. Means by which water, heat and dissolved materials transit laterally between the shelf-slope regions and the interior basins, and vertically through the halocline and upper mixed layer, have been of special interest.

OBJECTIVES

Five primary objectives contribute to the above goals.

- Document mean circulation patterns in the Arctic, with emphases on currents which transport heat and dissolved materials from the eastern to the western Arctic and on discharge of shelf waters northward into the interior basins.
- Quantify, insofar as possible, mean current speeds associated with the slope and deep ocean currents.
- Estimate the horizontal distributions of vertical heat and salt flux through the Arctic Ocean halocline.
- Assess the nature and distribution of observed upper ocean mesoscale features, including eddies and frontal systems, and estimate their influence on horizontal and vertical upper layer heat fluxes.
- Investigate the interactions among small-scale mixing processes and mesoscale features, and assess the influence of these interactions upon the mean distributions of temperature, salinity and dissolved materials.

APPROACH

This project has utilized newly and recently collected field data, subjected to both classical and state-of-the-art analysis methods, to approach the above objectives. This approach is in large part a response to the general lack of high quality oceanographic data from the Arctic Ocean. It also reflects an increasing need for improved parameterization and validation information for numerical models that are currently being

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developed to describe the behavior of ice and water in the Arctic. The primary approach for the past year has been acquisition of new field data using a U.S. Navy nuclear submarine as a sampling platform.

WORK COMPLETED

During the past year, I participated as Chief Scientist for the SCICEX 98 deployment aboard the U.S. Navy submarine *Hawkbill*. This duty included participation in planning for the deployment, loading of scientific equipment aboard the vessel, and the deployment itself which lasted for about 3.5 months. Duties during the deployment included short-term decisions concerning scientific activities, data quality control, archiving and preprocessing.

Other completed work has included processing of temperature, salinity and current data obtained during the SCICEX 97 deployment aboard the submarine *Archerfish*. Preliminary results were presented at the 1998 AGU Ocean Science Meeting [Muench *et al*., 1998a] and at the 1998 assembly of the European Geophysical Society [Muench *et al*., 1998b]. Work continued on jointly authored papers, planned to be submitted to *Journal of Geophysical Research*, that address results from 1995 and 1996 oceanographic cruises to the eastern Arctic aboard the German research icebreaker *Polarstern*. Preliminary results from these cruises were presented at the 1998 Assembly of the European Geophysical Society [Schauer *et al*., 1998; Rudels *et al.*, 1998a]. Two papers concerning mixing processes that were presented at the spring 1997 Liège Colloquium on Ocean Hydrodynamics have been accepted for publication in the Proceedings Issue of *Journal of Marine Systems* [Dewey *et al*., 1998; Rudels *et al*., 1998b]. I presented a summary of this work as an invited talk at the AGU Ocean Sciences meeting [Björk *et al.*, 1998].

Finally, I continued to serve as Chair of the Scientific Working Group for the SCICEX program. The second annual meeting of this group was held in conjunction with the Fall 1997 AGU meeting in San Francisco.

RESULTS

Several intriguing results have emerged from preliminary processing of the data obtained during the SCICEX 98 submarine deployment. Integration of these early results with those gained from the ongoing analyses of previous years' data has both added to our knowledge of the Arctic Ocean and identified gaps in our existing knowledge.

The warming trend that has been apparent at mid-depths in the Arctic Ocean over the past decade [Carmack *et al*., 1995] has continued through summer 1998. A comparison between data obtained over the Siberian continental slope in the Makarov Basin in 1998 and that taken in 1996 shows that maximum temperature was about 0.25ºC higher in 1998. This comparison was made in the slope current that transports water east into the Canadian Basin. The higher temperatures in this current imply that temperatures will continue to rise farther east in the Canadian Basin.

A detailed survey carried out at 220 m depth over the northern Arctic Mid-Ocean Ridge (also referred to as the Nansen-Gakkel Ridge in this region) revealed a strong frontal structure aligned along the Ridge axis. Temperatures in excess of +2ºC were observed south of the front, and a preliminary estimate based on the ship track suggests an along-front current having speeds of several tens of cm s^{-1}. Neither the high temperatures nor the currents are consistent with the presently accepted hypothesis, based on Rudels *et al*.,

1994], concerning circulation in this area. These new data will improve our understanding of circulation in the region and may also, since the warm source water for the Arctic Ocean is involved, impact our assessment of the interactions among the Arctic Ocean and global climate changes.

A detailed survey was carried out, for the first time, of the frontal structure between Atlantic and Pacific water masses that coincides roughly with the Alpha-Mendeleyev Ridge system. Structure was seen to be complex in response to a widely varying bottom topography, and was nearly 200 km in cross-frontal extent.

We acquired more than 140 vertical profiles of temperature and salinity, a large number of which show vertical inversions associated with the subsurface warm core. Occurring across the entire Arctic Ocean, these features probably originate within zones of horizontal gradient and evolve through double diffusive processes [e.g., May and Kelley, 1997]. These profiles add to a data set that includes previous SCICEX and surface vessel data and result in excellent horizontal coverage of much of the Arctic Ocean. This combined data set is adequate for mapping the distribution of inversion features and for determining their spatial relationships to known frontal and circulation systems. Our understanding of these features is improving due both to published laboratory and theoretical results and to the availability of new field data. They may play a significant role in both vertical and lateral heat fluxes in the interior Arctic Ocean, which is a region of atypically low turbulent energy.

IMPACT/APPLICATION

Data obtained during the summer 1998 *Hawkbill* deployment have shown that the subsurface warming trend in the Arctic Ocean has continued at least to August 1998. At the same time, upper layer salinity along the Siberian continental slope was seen to be lower than previously. Ice cover was noted to be less in 1998 than for previous years, as well. Longer-term implications for interannual changes in the subsurface waters and for the ice cover are unclear. Possible impacts include significant ice cover variations over the next few years, with concurrent impact on Arctic submarine operations. Additionally, the upper ocean salinity and temperature fluctuations are modifying the acoustic environment through their influence on sound velocity. The region therefore remains of interest both from the viewpoint of climate change and from Naval operational viewpoints. Efforts are currently underway with numerical modelers in an attempt to provide more representative model parameterization and to validate model results, in the hope that a reliable predictive model can be developed. Finally, it is anticipated that new insight will accrue from analyses of the temperature and salinity inversions and that this insight will be applicable to small scale, low energy processes at other locations in the World Ocean. The Arctic Ocean is, because of its generally low kinetic energy, a good natural laboratory for such processes.

From an operational viewpoint, the 1998 *Hawkbill* deployment clearly demonstrated the scientific potential of an instrumented submarine used in an intensive horizontal profiling mode. The combination of closely spaced horizontal track lines and expendable vertical profilers allowed mapping for the first time of oceanographic conditions associated with a well defined front along the Arctic Mid-Ocean Ridge. It was also possible to assess in detail the conditions associated with the complex frontal system that overlies the Alpha-Mendeleyev Ridge and which may play a pivotal role in the present Arctic Ocean warming trend.

TRANSITIONS

Currents and distributions of temperature and salinity derived from the field work are being compared with Arctic Ocean model results compiled by Wieslaw Maslowski (U.S. Naval Postgraduate School) in an attempt to improve the model's capabilities and reliability.

RELATED PROJECTS

1 - Portions of this project are coordinated with other ongoing work funded under the auspices of the interagency SCICEX (Submarine-based Arctic Science) program. Chemistry (Terry Whitledge, Univ. of Alaska) and tracer (Bill Smethie and Peter Schlosser, Columbia Univ.) results are being used, in particular, in conjunction with hydrographic and current data to assess circulation and mixing processes. Interannual change is being addressed jointly with Pete Mikhalevsky (Science Applications International. Corp.). Analyses of the frontal systems observed during 1998 are being done jointly with Tim Boyd (Oregon State Univ.).

2 - The SCICEX data have allowed us to continue to track large-scale changes in the Arctic Ocean water column, and contribute to our understanding of the role of the Arctic Ocean in global climate change. SCICEX therefore shares and contributes to some of the goals of the WMO (World Meteorological Organization) WCRP (World Climate Research Program) ACSYS (Arctic Climate Systems) program.

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